AD-765 199

VFR APPROACH PROFILES IN THE T-38 AIRCRAFT

A. C. McTee

Bunker-Ramo Corporation

Prepared for:

Air Force Flight Dynamics Laboratory

June 1972

CONTROL - DISPLAY INTEGRATION PROGRAM

AFFDL-TR-72-110

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AIR FORCE/56780/23 July 1973 — 150

VFR APPROACH PROFILES
IN THE
T-38 AIRCRAFT

A. C. McTEE

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FOREWORD

This technical report documents the results of a study conducted under USAF Contract No. AF33(615)-69-C-1716, describing the landing approach profile of the T-38 aircraft under visual flight conditions. The objective of the study was to establish a characteristic VFR profile for reference in future evaluations of approach aids and revisions of instrument landing guidance systems.

The contract was initiated under Air Force Project 6190, "Control-Display for Air Force Aircraft and Aerospace Vehicles," which is managed by Mr. J. H. Kearns III, as project engineer and principal scientist for the Flight Deck Development Branch (AFFDL/FGR), Flight Control Division, Air Force Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio. The work was performed as a part of Task No. 6190 07 under the guidance of Mr. William Augustine (AFFDL/FGR) as task engineer. Dr. A. C. McTee, Program Manager, Human Engineering Group of the Electronic Systems Division, Bunker Ramo Corporation acted as principal investigator for the study.

The author wishes to extend recognition to the many people who made significant contributions to this effort: Lt. Col. D. M. Condra, USAF IPIS, who pointed out the need for these data; Mr. Cash Feindel, ASTDP, who operated the tracking theodolite; Mesdames L. A. Schultze and A. A. Garcia, who digitized the theodolite recordings; Dr. L. R. Stanlev, Trinity University, who provided the parameter computation program; and Mrs. Carol Berryhill, who did the final editing and typing. Without the energy and cooperation of these people, this work could not have been accomplished.

This technical report has been reviewed and is approved.

John H Kearns

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Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Bunker-Ramo Corp., Govt. Systems Group
31717 La Tienda Dr.
Westlake Village, Ca. 91361

2a. REPORT SECURITY CLASSIFICATION: Unclassified

2b. GROUP

3. REPORT TITLE

VFR Approach Profiles in the T-38 Aircraft

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5. AUTHOR(S) (First name, middle initial, last name)

A. C. McTee

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1972	~~36~~ 42	12

8a. CONTRACT OR GRANT NO.

AF33(615)-69-C-1716

b. PROJECT NO.

6190

c.

6190 07

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

AFFDL-TR-72-110

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

J0087-2U16

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

A.F. Flight Dynamics Lab.
Flight Control Div.
WPAFB Ohio 45331

13. ABSTRACT

This study presents tabulated data from the theodolite tracking of 334 VFR approaches in the T-38 aircraft. The objective of the study was to determine whether the VFR approach path was straight or was multiangular, as reference data for the development of a head-up display to aid VFR landing. The form of the normal VFR path has implications for the type of command--single-angle or segmented--to be provided by a landing aid. It is concluded that the path in the mile before touchdown is composed of at least three angular segments. The values of the angles for each segment remained remarkably constant across the thirteen approach conditions measured. Night approaches were consistently steeper, higher at threshold, and had longer landing distances than did day approaches under similar conditions. The data presented have strong implications for the geometry of instrument landing system guidance profiles, based on the observed differences in the VFR and IFR profiles below 200 feet altitude. The measured approach angles are steeper at moderate ranges, flatter at short ranges than the nominal IFR profile, reflecting favorably on the steeper angle approach for noise abatement but posing a potential flight safety problem in low threshold crossing heights. This report presents the most comprehensive set of data collected on the normal VFR profile for the T-38 aircraft.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Theodolite Tracking						
VFR						
T-38 Aircraft						
Head-up Display						
Visual Flight Rules						
Aircraft Landing						

*U.S.Government Printing Office: 1973 — 759-498/611

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CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES---Concluded

SECTION I

INTRODUCTION

Landing-short accidents in high-performance aircraft are perhaps the foremost aviation safety problem. The higher angles of attack and thrust-dependent paths required by the supersonic aircraft, coupled with less-than-optimum over-the-nose vision in some, create severe perceptual and workload problems for the pilot. It is frequently very difficult for him to see exactly where the aircraft is going, and to control the aircraft to maintain a stable visual approach path. For the less experienced pilot, this is even more true. The visual approach is affected by a number of visual illusions and hazards (1) including variables such as runway perspective and slope, sun, glare, obscuration, and visual contrast. The hazards of high sink rates at low altitudes are obvious; complicating matters further is the illusion, in restricted visibilities, of being higher than one really is. Obviously, the inexperienced pilot, or one unfamiliar with the weather environment, can get himself and his aircraft into a very serious box—even more so if the aircraft has unforgiving aerodynamic or performance charateristics.

Air Training Command, concerned over landing-short accidents in the T-38, requested that the Air Force Flight Dynamics Laboratory explore the development of a heads-up display device for use in VFR T-38 landings, to provide for the pilot command information for obtaining and maintaining an appropriate path in space. In 1969, AFFDL agreed to undertake this development, and Mr. Knemeyer of AFFDL subsequently conceived the Mechanical Path Angle Director Display (MEPADD), which appeared capable of providing vertical path commands during VFR landing.

In undertaking the specification of the path to be commanded, it was found that little actual information was available describing paths followed by T-38 and similar aircraft in landing. It was supposed, from observation, that the path flown was multi-angular, but little documentation of this was found. The present study, therefore, sought to determine whether the T-38 VFR profile was multi-angular or straight-line to establish a model for the tailoring of the landing aid director command, and to provide typical values for approach, threshold, and terminal path angles.

Quantitative data describing the approach profile were required (1) to define the path to be commanded by the VFR landing aid, and (2) to establish baseline performance levels against which approaches with the landing aid could be compared.

SECTION II

METHODOLOGY

The method by which these data were obtained has been described in detail in an earlier report (2). Very briefly recapping the data collection technique: a single phototheodolite was used to track T-38 aircraft making routine VFR training approaches to runway 14L at Randolph Air Force Base. Elevation and azimuth angles from the theodolite were used to compute height and range of the aircraft at intervals of one-half second for approximately the last mile of each approach. 334 approaches were so treated to obtain the data base. Computer output was in tabular form, listing height, range, ground speed, and aim point at one-half second intervals for each approach tracked.

1. PARAMETER COMPUTATIONS

The values of the approach parameters for this report were computed from the range and altitude figures derived from the theodolite tracking, with appropriate selection of points. Ten pairs of range/altitude values were extracted from the theodolite printout, working backward from touchdown; these were:

(1) At touchdown

(2) One second before touchdown

(3) First data point inside threshold

(4) Last data point before threshold

(5) Data point just below 50 feet altitude

(6) Data point just above 50 feet altitude

(7) Data point just below 100 feet altitude

(8) Data point just above 100 feet altitude

(9) Data point just below 2000 feet range

(10) Data point just below 4000 feet range.

Linear interpolation was used to define threshold, 50-foot and 100-foot points. Path angles were computed from the touchdown/1 second prior to touchdown, inside threshold/outside threshold, and 2000/4000

foot values, to establish, respectively, terminal, threshold, and approach path angles. The 2000/4000 foot values were selected arbitrarily; since most of the aircraft were turning on to final at 6000 feet, the 4000 foot range was chosen to allow the aircraft to be on a stabilized final, and the 2000 foot range was felt to be far enough out to eliminate any early flares from the approach data.

A hypothetical ILS glide slope of 2.5 degrees to a glide path interception point (GPIP) 1250 feet down the runway was assumed for purposes of comparison. This hypothetical glide slope would cross the threshold at a nominal altitude of 55 feet; thus the figures of 1250 feet GPIP and 55 feet are the ILS referents for parameters 3 and 11 (see Table I).

2. CONDITIONS

The population of 334 approaches was classified into conditions based on four dichotomous categories: solo/dual, touch and go/full stop, day/night, overhead/straight in. Sixteen conditions were thus possible, but only 13 were represented in the tracked approaches. Five of the 13 included three or fewer approaches, and thus did not achieve stable statistical representation. Table II lists the conditions and the number of approaches sampled for each. It can be seen that the straight-in conditions are much less well represented than the overhead conditions, and that almost two-thirds of the approaches are overhead/dual/day. This imbalance is unintentional, but simply reflects the relative proportions of the several approach types flown during the tracking periods. It will be desirable, in future investigations, to selectively sample so that stable representation can be achieved for all conditions.

Values for the computed parameters for each of the conditions are tabled in the Appendix.

3. DATA FORMAT

The format for presentation of the data has been adapted from Litchford (3). We feel that much utility is gained if investigators will adopt common formats for data presentation, so that comparisons of findings may be more easily made. Different aircraft types probably do not behave alike, and it makes little sense to obscure the differences by using varied formats for data presentation without compelling reason.

Table I lists the sixteen parameters or variables computed for each approach (or group of approaches under a condition). The sixteen variables "cluster" in descriptions of the approach (1-2); relationships of approach points to touchdown, threshold, or ILS GPIP (3-8); threshold situation (9-11); touchdown performance (12-13); and relationships of paths during approach, threshold crossing, and just before touchdown (14-16).

Table I. Computed parameters

1. Approach Path Angle
2. Approach Aim Point
3. Aim Point to ILS Glide Path Intercept Point
4. Aim Point to Touchdown
5. 100' Altitude to Threshold
6. 100' Altitude to Aim Point
7. 100' Altitude to Touchdown
8. 50' Altitude to Threshold
9. Threshold Crossing Height
10. Threshold Path Angle
11. Distance Below Nominal ILS Height at Threshold
12. Touchdown Distance
13. Terminal Path Angle
14. Ratio, Approach Path Angle to Threshold Path Angle
15. Ratio, Approach Path Angle to Terminal Path Angle
16. Ratio, Threshold Path Angle to Terminal Path Angle

Table II. Number of approaches for each condition

Overhead								Straight In							
Touch and Go				Full Stop				Touch and Go				Full Stop			
Solo		Dual		Solo		Dual		Solo		Dual		Solo		Dual	
Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
22	18	97	28	21	3	108	13	1	0	3	1	1	0	18	0

SECTION III

RESULTS

1. OBSERVED VFR PROFILE

Figure 1 shows, in general, the difference between the VFR path and the geometry commanded by ILS guidance. One representative approach (#213) was selected from our sample to illustrate the different characteristics of the two profiles. Note that the VFR approach is much steeper than the ILS path to a point just outside threshold, but is much flatter from threshold to touchdown. The "glide path intercept point" for the VFR path is outside the threshold until flare, and the visual path is below the supposed 2.5 degree glide path for more than 3000 feet before threshold. Approach 213 crossed the threshold at about 11 feet altitude, and touched down just over 1000 feet past threshold.

2. PATH SEGMENTING

Arrows have been drawn in Figure 1 to indicate the approximate projection of segments of the path of Run 213. Note that the initial aim-point is some 1500 feet short of the runway, and is maintained to about 200 feet altitude. The flight path then is changed to a shallower angle, with an aim point about 200 feet short of the runway threshold. The flare begins outside the threshold, at about 30 feet, passes over threshold at about 11 feet, and results in a terminal angle of about 1/2 degree to touchdown.

We chose to avoid the question of attempting to define the path segments, preferring instead to express values for the path angles during approach, at threshold, and just before touchdown (see Figure 2). The differing values for these angles within conditions, and their consistency across conditions, are evidence that the approaches are composed of definite segments.

3. VFR/IFR PROFILE DIFFERENCES

The most significant differences in the VFR and IFR profiles are (1) the segmented nature of the visual profile, (2) the steeper visual approach path; and (3) the lower visual path in the half-mile before the runway. The determination of the exact number of segments in the apprich can be somewhat arbitrary, depending on how short a portion of the path you are willing to consider as a segment. Depending on the accuracy with which a particular approach hits the "400 feet at one mile" point, the length and angular deviation of the corrections will vary. The time from the one mile point to touchdown is only about 20-25 seconds, and this places an upper limit on the number of segments which can be

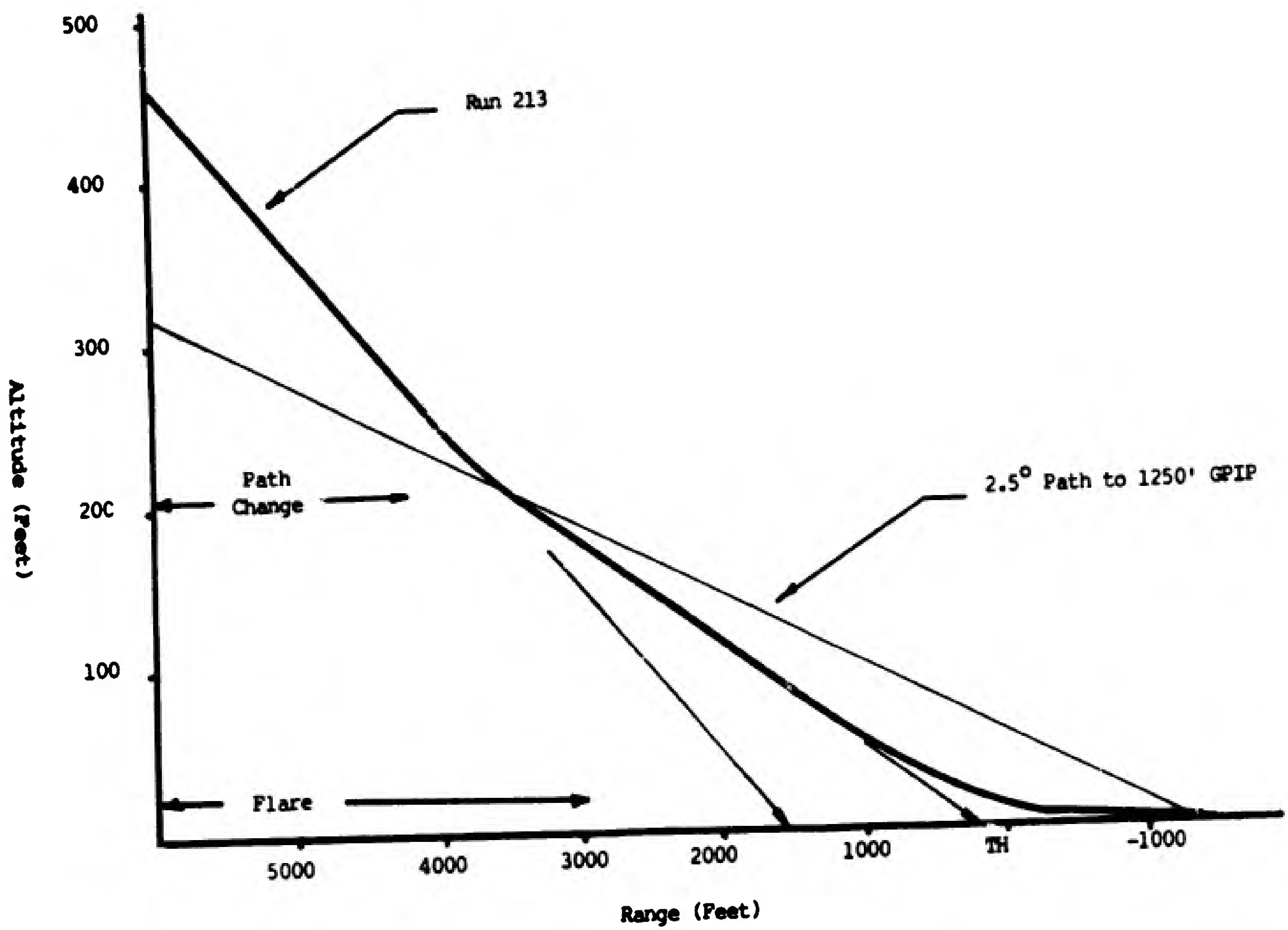

Figure 1. Paths for Run 213 and ILS Geometry

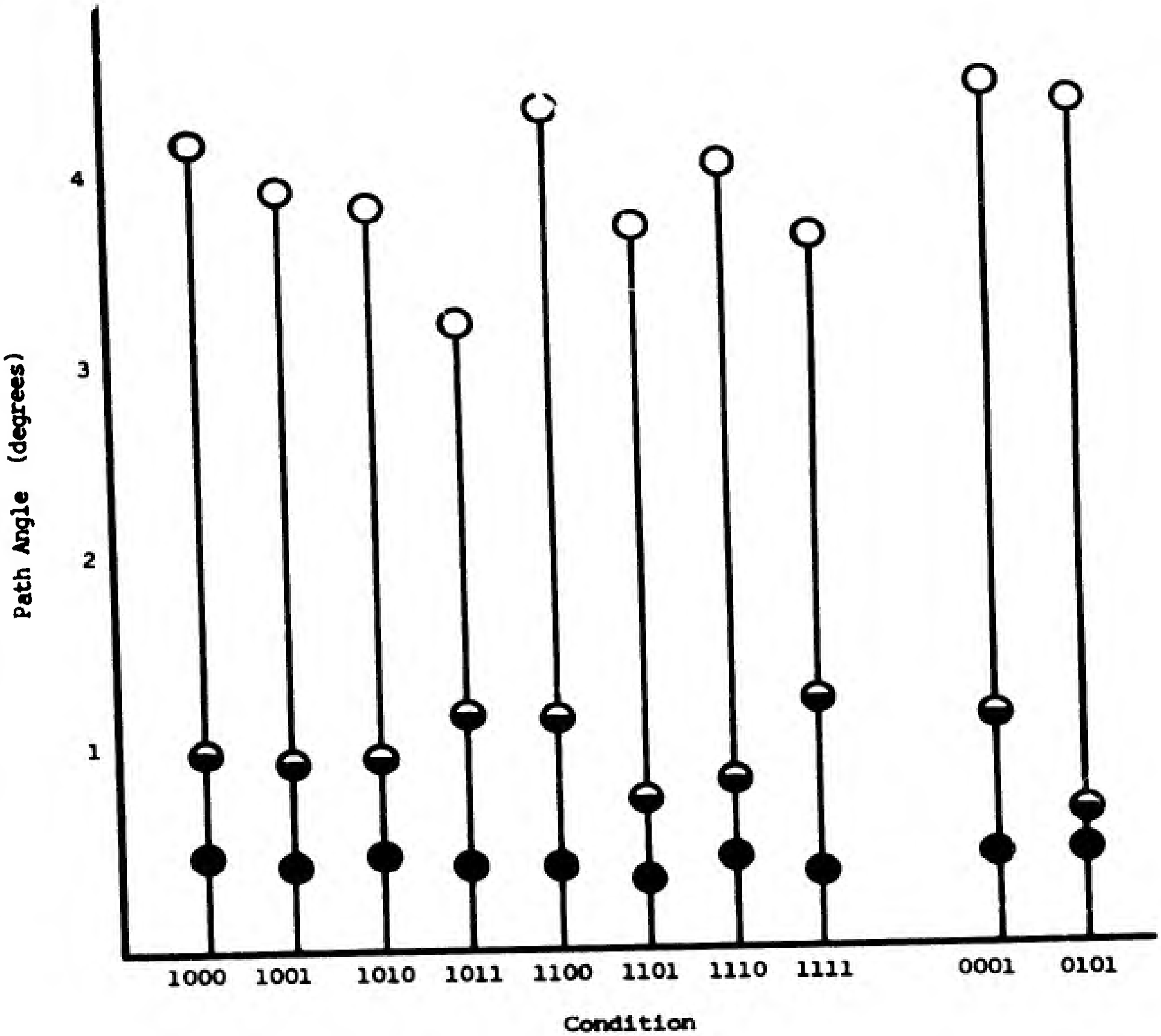

Figure 2. Means for Approach Angle (open circles), Threshold Path Angle (split circles), and Terminal Path Angle (filled circles) for the Conditions (see text for key to condition identifiers)

flown. The sequence of (1) estimating path; (2) making a correction; and (3) determining the new path takes perhaps 5 seconds. Therefore, we will probably see no more than two or three real flight path segments in the mile of the approach preceding flare.

A molecular analysis of the approach to define precisely what is a segment, and what their sequence may be, will require further study, with the benefit of onboard recording of pilot input to detect intentional path variations.

4. COMPARISONS BETWEEN CONDITIONS

It was intuitively felt that differences would be observed between some of the conditions — especially that solo and dual approaches might differ, and that touch and go approaches might show characteristics different from full stop landings.

Despite these intuitions, the conditions exhibit remarkably similar values for the computed parameters (see Table III et seq.). No condition differences even approach statistical significance. The sole consistent tendency was for night approaches to be steeper, to cross the threshold higher, and to land longer than did the day approaches. (This statement is based on overhead approaches only; the sample included only one night straight-in approach.) Figures 2 and 3 show the consistency of the day/night differences; it should be emphasized that these differences are small, and no attempt has been made to estimate their practical significance.

The frequency distribution of all touchdown distances, as mentioned in our earlier report (2), is remarkably "normal" in form, with a mean of 867 feet, and mode of 834 feet. The computed mode was selected because of a "mesa" in the 700 to 1000 foot range. The standard deviation was computed to be 269 feet. Mean touchdown distances for the conditions described here all fell within ± one standard deviation of the grand mean.

Tables III through XII, in the Appendix, present the parameters computed for the various grouped approaches.

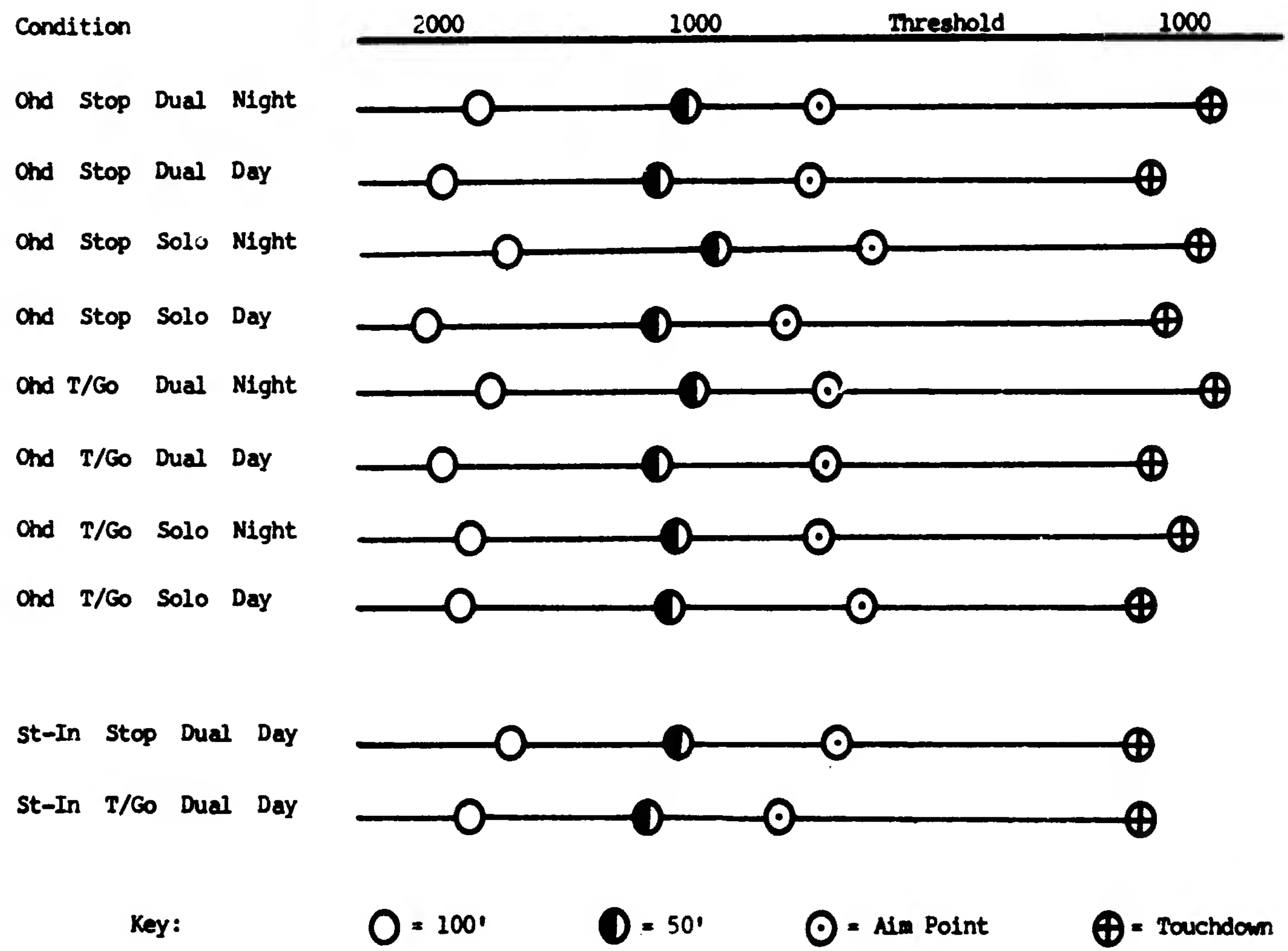

Figure 3. Mean Values Key Points for the Conditions (the runway is to the right)

SECTION IV

DISCUSSION

1. HOW THE VFR APPROACH IS FLOWN

Since the sample of T-38 approaches which form this data base were routine training approaches, it seems appropriate to extract from the training manual the instructions for the flying of the VFR approach. The following extract, somewhat edited, is from ATC Manual 51-38, Advanced Flying, Jet (Ref. 5), pp 25-30:

NORMAL PATTERN

To begin the final turn, enter a 30°-45° banked turn (45° maximum bank throughout the turn) with a relatively shallow rate of descent. Attain the final turn airspeed as soon as possible and maintain it until wings level on the final approach.

Complete rollout on final approach approximately 1-1/4 nautical miles from the end of the runway. Maintain sufficient altitude to establish a proper final approach angle that passes through 400 feet above the terrain at one nautical mile from the runway. After rolling wings level on the final approach, reduce to final approach airspeed soon as possible. Maintain final approach airspeed with power while keeping the aircraft on the proper approach angle.

(Ed. note: A reference to a figure in the original notes that the overrun should appear in the middle of the windscreen at approximately one nautical mile from touchdown.)

Use trim to relieve excessive stick forces throughout the landing pattern. You do not need to use the speed brake in the landing pattern.

NORMAL TOUCHDOWN

The T-38 is already in a partial landing attitude when you have established the proper final approach. As you approach the runway threshold, begin power reduction to arrive over the threshold approximately 10 knots below the proper final approach airspeed. Power and pitch changes from this point until touchdown depend on height above the runway, sink rate, and airspeed rate of change. Touchdown should occur at 130 KIAS plus fuel.

STRAIGHT-IN APPROACH

Arrive at the designated entry point 1000 feet above the terrain at 240 KIAS, if not otherwise specified.

At approximately five nautical miles from the end of the runway, establish the landing configuration (60% flaps for single-engine) and allow the airspeed to gradually decrease to final approach airspeed. The approach should be planned so that afterburner is not required to maintain the recommended airspeed.

Approximately two and a half nautical miles from the runway (for 1000-foot AGL pattern), begin descent planning to reach one nautical mile from the runway at 400 feet above the terrain if 60% or more flaps are used. (With less than 60% flaps, altitude above the terrain at one nautical mile should be approximately 300 feet.)

2. COMMENTS ON THE EXTRACT OF ATCM 51-38

Note that the material quoted does not direct an aim point. The T-38 Instructor's Guide (ATC Study Guide F-V5A-B-IT-SG) does, however, call out 500 feet short of the runway as a good aim point. This aim point, coupled with the 400 feet altitude at 1 NM from the runway specified in the ATCM 51-38, establishes an approach angle of approximately 4.2 degrees to the center of the overrun on Runway 14L.

The extract does not mention multiple angles for the approach; however, the instructions in the paragraph on Normal Touchdown, calling for power reduction "as you approach the runway threshold" appear to direct a path change based on pilot judgment.

The recommended touchdown speed of "130 KIAS plus fuel" means 130 knots reference speed, plus 1 knot for each 100 pounds of fuel over 1000 pounds remaining.

3. DESCRIPTIONS OF THE VISUAL APPROACH

a. Sensitive Parameters

A consideration of the parameters listed, in Tables III through XII (Appendix), leads to the opinion that these approaches can be fairly well described with five parameters: (1) approach path angle; (2) approach aim point; (3) threshold path angle; (4) threshold wheel height; and (5) touchdown distance. Most of the other tabled parameters can be considered supplemental to these five.

b. Variations in Airspeed as a Function of Altitude

In structuring the approach, the path angles in combination with the approach airspeed for the aircraft of course determine rates of descent. The approach path, with T-38 speeds, averages 1000-1200 FPM rate of descent at 155-175 knots, decreasing to perhaps 150 knots and 300 FPM descent passing the threshold. Some further deceleration and reduction in sink rate is accomplished over the runway, as ground effect is encountered.

c. Multiangular Paths

The path is definitely composed of several angular segments — perhaps actually more than the three we measured. The approach path, from our measurements, is approximately four degrees to an aim point 500 feet short of the threshold. By threshold, the path angle has been reduced to one degree, and to one-half degree for the path just before touchdown. These values are quite constant across all the measured conditions (see Figure 2).

d. Touchdown Distance as a Function of Aim Point

The aim point selected for the approach seems to be the primary determinant of the touchdown; in instrument approaches as well as in the present data, aim points typically are about 1500 feet short of the eventual touchdown point. In our data, aim points 500-600 feet short of the runway produced touchdown predominantly 700-1000 feet down the runway; references 3, 4, and 6 mention GPIP-to-touchdown distances of over 2000 feet in some IFR operations, meaning that a 1250-foot GPIP plus 2000 additional feet of flight would result in a 3250-foot touchdown — or perhaps one-third of the runway already behind the aircraft at touchdown.

e. Threshold Wheel Height as Expression of Pilot Confidence

Threshold wheel height represents, to some degree, the pilot's confidence in the approach. If all seems to be in order, the VFR pilot seems to prefer around 10 feet height over threshold — at least this seems to be a modal value in our data; reference (6) finds a mean threshold height of 20 feet in transport-class aircraft. In any case, the more confidence the pilot has, the lower he is likely to fly. T-38 instructor pilots have reported that they fly lower over the threshold when flying the front seat of the T-38, because visibility is better. They also say that they will be higher at night, and, interestingly enough, the night/day conditions we measured bear this out. Further supporting the "confidence" hypothesis are the data on threshold height from Tables VII and VIII, night and day overhead solo full stop approaches. Although the night data are lightly

represented, their mean is some six feet higher than the corresponding daylight approaches, the largest difference for any pair of conditions. It would seem reasonable that the student pilot, solo, might be somewhat less confident in his night solo flying than in either day solo or in dual instruction, and the data tend to support this line of reasoning.

f. Touchdown Distance as General Indicator of Success

Touchdown distance is to some extent the measure of success in landing, since the pilot generally wishes to get down as early as he safely can. The landing distance is a complex function of threshold crossing height, speed, and acceptable touchdown vertical velocity, plus some variance due to pilot technique and environmental or procedural conditions. The pilot strikes a cautious balance of these factors; despite the desire to land early, there is an old saying among pilots, "Land long and hurt yourself; land short and kill yourself." In operation, this means that some minimum height over threshold will be maintained for the sake of safety, and this in turn implies that some minimum length of concrete will always be behind the wheels at touchdown.

4. KEY POINTS FOR CONSIDERATION

Returning to our initial objective of providing structuring for the vertical approach path, certain points of the data deserve special attention in view of their implications for extension of the visual approach profile to other uses such as noise abatement or model for future instrument approach profiles. These points, it must be emphasized, are not the result of any experimental manipulations; these data merely describe operational training approaches, the pilots being unaware that the approaches are being tracked. It is thus felt that these data represent real operational practices and should be so considered.

a. Altitude Over Threshold

These aircraft cross the runway threshold quite low, and on a relatively flat flight path. Threshold wheel heights average around 10 feet. The flight path has already been "broken" before threshold to a value just over or under 1° at threshold.

b. Step Change in Path at Flare

The approach path appears to change in a stepwise fashion at the flare, and to a lesser degree, to the terminal angle. These "steps" do not appear in the collective data, perhaps because they are blurred by the variability of VFR flare points and pilot technique. Visual observation of a number of T-38 approaches, however, will verify this assertion. Some approaches appear to be flown as a series of plateaus: level flight; a short, relatively steep descent; level flight; and so on. Since these are

training approaches, it may be that this "plateau" technique is only a stage of learning proper vertical path control; we have not been able to substantiate this possibility. In any case, the flare appears as a definite upward break in the flight path, with similar changes frequently occurring low over the runway. A few approaches in this sample even had upward vertical paths at threshold; these could be "overflares," or simply the salvaging of a too-low approach.

c. Multiangular Path

The approach paths observed show definite multiple path segments. The three intervals over which path angles were measured produce path angles averaging approximately 4°, 1°, and 0.5° respectively for approach, threshold, and terminal segments. Observations of individual approaches show angle changes within the approach in some cases. However, the time required to cover the mile between turn to final and flare averages only 20 seconds or so, and the time for path correction is very limited. The after-the-fact designation of segments within this mile is somewhat arbitrary, and the difference between a deliberate attempt at a particular angle, and a corrective path back to a desired angle, may be impossible to resolve on the basis of external path measurements.

d. Aim Point

The approach aim points (which correspond to the glide path intercept point in instrument flying terminology) are approximately 500 feet outward from the runway threshold, some 1300-1600 feet before touchdown. Litchford (3) discusses (p 37) the relationships of glide path intercept point, touchdown distance, duckunder, and sink rate, and concludes that the GPIP should be moved forward perhaps 1000 feet for transport aircraft and 2000 feet for fighters. Interestingly enough, the aim points observed here are 1750 feet forward of the nominal ILS GPIP. This aim point is called out by training directives (and, from the data, is closely adhered to).

e. Day Versus Night

The differences in day and night approaches have been mentioned previously; night approaches tend to be steeper, to cross the threshold higher, and to land further down the runway. These tendencies are contrary to the findings of a study by Lewis and Humphries (7), which found that Canadian Navy pilots tended to approach slower and lower, and to land harder and shorter, by night than by day. Brictson, Hagen, and Wulfeck (8) also report that U.S. Navy pilots flew higher day than night approaches, but that more night approaches resulted in "bolters" (when the aircraft failed to engage the arresting gear); these findings held for five aircraft types observed in their study. The investigators hypothesize that the higher incidence of bolters at night is a result of absence of visual cues; the pilots

may be "ramp shy," preferring a high approach and consequent hard landing to a possible ramp strike. In daylight, with visual cues available the high approach can be "saved" by diving at the deck; in the night approach, when this "save" may not be feasible, the bolter results. The consistently steeper night approaches in our data are thus at variance with (7) and (8), and no rationale for the difference immediately comes to mind. It may be that Navy-trained pilots, emphasizing carrier operations, simply fly night approaches differently.

f. Restrictions on Generality of this Data Base

Since most of the reported data are from overhead approaches, the reported approach path angles are taken at the relatively short range of 2000-4000 feet from threshold. We recognize that the longer straight-in approach might be a different angle; however, our observations of grouped approaches have noted a constant decrease in variability of height (hence angle) as the range from threshold decreases. Therefore, we feel that, given measurement in the 2000-4000 feet range interval, path angles for overhead and straight-in approaches would not differ significantly. This is true for our collected data; approach angles for straight-in approaches are only slightly steeper than for other conditions (see Figure 2). A further series of measurements will be required to confirm or contradict this hypothesis.

Approach aim points in these data are constrained, as previously mentioned, by training directives which call for an aim point 500 feet outside threshold. These directives probably restrict the variability of the aim points somewhat as compared to a situation in which each pilot might be free to choose his own aiming point. These approaches were flown to a runway with an overrun of 1000 feet; different results might be observed on a runway without overrun or a very long runway where stopping distance was not expected to be critical.

Training directives also suggest that touchdown should be accomplished in the first 1000 feet of runway (ref. 5, p 23). This instruction quite likely limits the distribution of touchdown points and produces a more "normal" distribution of touchdowns (ref. 2, p 10) than was found by Geoffrion and Kibardin (6). Their obtained distributions for touchdown distance were markedly skewed in the down-runway direction. For whatever reason, the touchdown distribution for the aircraft we observed is almost "textbook" normal.

SECTION V

IMPLICATIONS

1. CHARACTERISTICS OF THE VFR PROFILE

From these observations, we conclude that the VFR profile is composed of multiple angles; that it crosses threshold quite low and flat; and that night approaches tend to be steeper. For the design of approach aids, therefore, a decision must be made as to whether the VFR path should be used as a model for the command. If so, then precise values for the angular segments and their "break points" must be established.

2. THE VFR PROFILE AS MODEL FOR THE IFR PROFILE

The standard IFR profile, as presently structured, places the aircraft above our measured VFR path below about 200 feet altitude. This path difference has been postulated as a contributing cause for the "duckunder" in low-visibility conditions. With prevention of duckunder as one objective, George Litchford (3, 9, 10) has presented a persuasive case for patterning the instrument approach guidance path after the visual profile.

A bit of caution is desirable, however, in the adoption of the visual path as a model until testing can be performed. The low altitudes in the near-threshold profile leave little room for errors on the low side of the path. We have little or no operational experience with operations on IFR paths which do not allow errors in both directions. The VFR profile, however, seems to establish a lower bound for flight in the region just preceding runway threshold. Precautionary measures, in techniques of control and of display, appear to be required before the implementation of guidance for this low path.

The segmented approach, for example, has been proposed for noise abatement; in this concept, a 6° path would be flown to 400 feet altitude, where a change to 3° would be accomplished. Airline pilots do not like this approach on instruments, citing the high rates of descent in the 6° portion as particularly dangerous. In an earlier AFFDL-directed study, pilots flying dual angle approaches against the AILS system reported that the transitions between angles were extremely difficult to accomplish using standard flight director commands and displays (Ref. 12). These experiences indicate that a considerable effort may be required to develop appropriate displays and command computation functions for the multiple-angle approach. Apparently, the mere substitution of "crooked" guidance for the linear beam will not result in an adequate system.

3. THE VFR PROFILE AND THE LARGE AIRCRAFT

The report by Geoffrion and Kibardin (6) is the best collection of data on VFR operations of jet transport aircraft. Since the publication of that report in 1962, however, the large jet aircraft such as the 747 and C-5 have entered operational service. The flight profiles for these large aircraft have not been collected in report form; however, one might surmise that the wheel path for these aircraft would not differ greatly from that of jet transports. One significant difference, observed in flight operations, is the relatively great displacement (perhaps 40 feet) of the pilot's eye path from the wheel path, and the differential effects of pitch changes on the eye and wheel paths. According to Ref. 11, a pitch change of 4 degrees nose up in the 747 moves the pilot's station 6 feet upward, while the undercarriage moves 8 inches lower. This has obvious effects on the pilot's ability to maintain proper height above threshold; Ref. 11 is an account of an incident in which a 747 struck short of the runway, and presents an excellent discussion of the issues in visual landing of the large aircraft.

4. NEEDS FOR FURTHER DATA

a. Other Types of Aircraft

The 747 and C-5 are not especially similar to the T-38 aircraft from which our data were derived; and data describing their characteristic profiles in operational service are needed, to represent the large aircraft classification. This representation must include both day and night approaches. The Geoffrion and Kibardin measurements (6) should be extended to night operations for the medium-sized jet transports.

b. Augmentation of Straight-In and Night Approach Samples

Our T-38 data should be augmented by measuring straight-in approaches, and more night operations, to give a more comprehensive description of the profile under all visual approach conditions. Complete and accurate documentation of the VFR profile for all aircraft classes is an urgent need, to promote understanding of the landing maneuver as a step toward safer and more precise landing operations for both VFR and IFR conditions.

c. Consideration of the Total Approach

We think that the VFR landing approach in high-performance aircraft is very much affected by what has happened further back in the profile; that performance of the base leg and the final turn, and perhaps even the downwind leg, may in some part determine the goodness of the final approach. The aircraft which rolls out of the final turn high or low, or off alignment or airspeed, is likely to be difficult to stabilize on an acceptable path to the runway. As previously mentioned, the time available

for correction is limited; additionally, the margin for maneuver is very small, as, for example in attempting to correct an overshoot in the final turn. We are continuing, under AFFDL/FGR direction, further studies of the final approach profile, aided with flight path display as well as in normal VFR operation.

SECTION VI

APPENDIX

A. LIST OF TERMS USED IN THE TABLES

The tables following give descriptions of performance and variability for each of the conditions which contained three or more approaches. The number of approaches for each is listed in the heading, with the condition description. The condition code is as follows: first digit, 1 = overhead, 0 = straight in; second digit, 1 = touch and go, 0 = full stop; third digit, 1 = solo, 0 = dual; fourth digit, 1 = day, 0 = night. The terms used for each parameter are as follows:

(1) Approach Angle—the descent angle between 4000 and 2000 feet range points. A positive value indicates a descent.

(2) Approach Aim Point—the range at which the approach path, as defined by the 4000/2000 foot ranges and their associated altitudes, would reach zero altitude if continued. Positive values are outside the runway threshold, short of the runway.

(3) Aim Point to ILS GPIP—the distance from the approach aim point to a hypothetical ILS glide path intercept point (GPIP) 1250 feet inside threshold. Positive values indicate that the aim point was short of the GPIP.

(4) Aim Point to Touchdown—the distance from aim point to the touchdown point (always positive).

(5) 100 Feet to Threshold—the range at which the aircraft passed through the 100 foot altitude (always positive).

(6) 100 Feet to Aim Point—the range difference between the aim point and the range where the 100 foot altitude was reached. A positive value means that the 100 foot point was farther from threshold than the aim point.

(7) 100 Feet to Touchdown—the distance from the 100 foot point to touchdown.

(8) 50 Feet to Threshold—the range at which the aircraft passed through 50 feet altitude. Positive values indicate that the 50 foot point was passed before threshold.

(9) Path Angle at Threshold—the vertical path angle for the one-half second interval in which the threshold was passed. Positive values indicate a descending path, negative values a climb.

(10) Threshold Crossing Height—wheel height at threshold.

(11) Amount Below ILS at Threshold—the difference between threshold crossing height and the height of a hypothetical ILS glide slope of 2.5° to a 1250 foot GPIP (height at threshold: 55 feet). The deviation figure is the distance from the center of the hypothetical beam to the measured threshold crossing (wheel) height.

(12) Terminal Path Angle—the vertical path angle for the last second before touchdown.

(13) Touchdown Distance—the distance down the runway at touchdown. The zero point is at threshold and all values are positive.

(14) Ratio of Approach Angle to Threshold Path Angle—this ratio indicates the amount of change in flight path before threshold. Negative values may sometimes occur; these indicate a climbing path at threshold.

(15) Ratio of Approach Angle to Terminal Angle—this ratio indicates the magnitude of path change from approach to touchdown.

(16) Ratio of Threshold Path Angle to Terminal Angle—this ratio represents the magnitude of path change between threshold and touchdown. Negative values indicate a climbing path at threshold.

Table III. Straight in/full stop/dual/day condition

Condition 0001
N=18

Parameter	Unit	Mean	Standard deviation
1. Approach Path Angle	deg.	4.54	0.74
2. Approach Aim Point	ft.	474	347.7
3. Aimpoint to ILS GPIP	ft.	1724	347.7
4. Aim Point to Touchdown	ft.	1266	397.0
5. 100' to Threshold	ft.	1774	254.1
6. 100' to Aim Point	ft.	1301	219.9
7. 100' to Touchdown	ft.	2567	367.7
8. 50' to Threshold	ft.	1037	217.1
9. Threshold Path Angle	deg.	1.20	0.65
10. Threshold Wheel Height	ft.	9.6	4.2
11. Amount Below ILS at Th	ft.	45.4	4.2
12. Terminal Path Angle	deg.	0.48	0.24
13. Touchdown Distance	ft.	793	265.7
14. Ratio: Approach Angle/TH Angle		5.43	4.83
15. Ratio: Approach Angle/Terminal Angle		12.35	6.97
16. Ratio: Threshold Angle/Terminal Angle		2.93	1.73

Table IV. Straight in/touch and go/dual/day condition

Condition 0101
N=3

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	4.42	0.39
2.	Approach Aim Point	ft.	660	172.3
3.	Aimpoint to ILS GPIP	ft.	1910	172.3
4.	Aim Point to Touchdown	ft.	1422	99.2
5.	100' to Threshold	ft.	1951	234.7
6.	100' to Aim Point	ft.	1291	148.1
7.	100' to Touchdown	ft.	2713	114.6
8.	50' to Threshold	ft.	1219	217.1
9.	Threshold Path Angle	deg.	0.69	0.52
10.	Threshold Wheel Height	ft.	7.67	2.61
11.	Amount Below ILS at TH	ft.	47.3	2.61
12.	Terminal Path Angle	deg.	0.48	0.12
13.	Touchdown Distance	ft.	762	120.9
14.	Ratio: Approach Angle/TH angle		10.0	4.80
15.	Ratio: Approach Angle/Terminal Angle		10.22	3.75
16.	Ratio: Threshold Angle/Terminal Angle		1.40	0.83

Table V. Overhead/full stop/dual/night condition

Condition 1000
N=13

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	4.2	0.35
2.	Approach Aim Point	ft.	499	139.6
3.	Aim Point to ILS GPIP	ft.	1749	139.6
4.	Aim Point to Touchdown	ft.	1589	442.1
5.	100' to Threshold	ft.	1854	165.5
6.	100' to Aim Point	ft.	1355	134.9
7.	100' to Touchdown	ft.	2944	458.9
8.	50' to Threshold	ft.	1015	128.9
9.	Threshold Path Angle	deg.	1.07	0.63
10.	Threshold Wheel Height	ft.	11.9	4.47
11.	Amount Below ILS at TH	ft.	43.1	4.47
12.	Terminal Path Angle	deg.	0.51	0.46
13.	Touchdown Distance	ft.	1090	415.02
14.	Ratio: Approach Angle/Th Angle		2.99	5.88
15.	Ratio: Approach Angle/Terminal Angle		16.22	13.04
16.	Ratio: Threshold Angle/Terminal Angle		3.86	3.39

Table VI. Overhead/full stop/dual/day condition

Condition 1001
N=108

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	3.97	0.76
2.	Approach Aim Point	ft.	519	323.8
3.	Aim Point to ILS GPIP	ft.	1769	323.8
4.	Aim Point to Touchdown	ft.	1353	367.7
5.	100' to Threshold	ft.	2027	242.9
6.	100' to Aim Point	ft.	1508	348.3
7.	100' to Touchdown	ft.	2861	356.5
8.	50' to Threshold	ft.	1157	180.0
9.	Threshold Path Angle	deg.	0.93	1.70
10.	Threshold Wheel Height	ft.	8.66	3.96
11.	Amount below ILS at TH	ft.	46.34	3.96
12.	Terminal Path Angle	deg.	0.44	0.22
13.	Touchdown Distance	ft.	834	305.9
14.	Ratio: Approach Angle/TH angle		4.20	4.84
15.	Ratio: Approach Angle/Terminal Angle		13.22	19.6
16.	Ratio: Threshold Angle/Terminal Angle		2.63	14.57

Table VII. Overhead/full stop/solo/night condition

Condition 1010
N=3

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	3.91	0.51
2.	Approach Aim Point	ft.	300	20.9
3.	Aim Point to ILS GPIP	ft.	1550	20.9
4.	Aim Point to Touchdown	ft.	1320	125.5
5.	100' to Threshold	ft.	1768	216.5
6.	100' to Aim Point	ft.	1468	237.2
7.	100' to Touchdown	ft.	2788	288.4
8.	50' to Threshold	ft.	899	121.8
9.	Threshold Path Angle	deg.	1.00	0.84
10.	Threshold Wheel Height	ft.	14.7	3.13
11.	Amount Below ILS at TH	ft.	40.3	3.13
12.	Terminal Path Angle	deg.	0.5	0.10
13.	Touchdown Distance	ft.	1020	133.4
14.	Ratio: Approach Angle/TH Angle		-9.18	17.02
15.	Ratio: Approach Angle/Terminal Angle		8.06	0.9
16.	Ratio: Threshold Angle/Terminal Angle		1.75	1.56

Table VIII. Overhead/full stop/solo/day condition

Condition 1011
N=21

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	3.27	2.05
2.	Approach Aim Point	ft.	625	611.2
3.	Aim Point to ILS GPIP	ft.	1875	611.2
4.	Aim Point to Touchdown	ft.	1633	844.3
5.	100' to Threshold	ft.	2085	250.9
6.	100' to Aim Point	ft.	1461	741.2
7.	100' to Touchdown	ft.	3094	679.1
8.	50' to Threshold	ft.	1150	157.1
9.	Threshold Path Angle	deg.	1.24	0.47
10.	Threshold Wheel Height	ft.	8.97	3.01
11.	Amount Below ILS at TH	ft.	46.0	3.01
12.	Terminal Path Angle	deg.	0.44	0.33
13.	Touchdown Distance	ft.	900	634.9
14.	Ratio: Approach Angle/TH Angle		3.83	4.85
15.	Ratio: Approach Angle/Terminal Angle		18.79	29.9
16.	Ratio: Threshold Angle/Terminal Angle		7.51	16.12

Table IX. Overhead/touch and go/dual/night condition

Condition 1100
N=28

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	4.41	0.62
2.	Approach Aim Point	ft.	478	265.2
3.	Aim Point to ILS GPIP	ft.	1728	265.2
4.	Aim Point to Touchdown	ft.	1579	357.4
5.	100' to Threshold	ft.	1807	209.8
6.	100' to Aim Point	ft.	1330	211.1
7.	100' to Touchdown	ft.	2908	335.5
8.	50' to Threshold	ft.	999	216.1
9.	Threshold Path Angle	deg.	1.22	0.73
10.	Threshold Wheel Height	ft.	11.9	4.36
11.	Amount Below ILS at TH	ft.	43.07	4.36
12.	Terminal Path Angle	deg.	0.41	0.22
13.	Touchdown Distance	ft.	1101	287.1
14.	Ratio: Approach Angle/TH Angle		2.42	23.9
15.	Ratio: Approach Angle/Terminal Angle		14.4	8.38
16.	Ratio: Threshold Angle/Terminal Angle		3.74	3.05

Table X. Overhead/touch and go/dual/day condition

Condition 1101
N=97

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	3.78	1.53
2.	Approach Aim Point	ft.	487	404.4
3.	Aim Point to ILS GPIP	ft.	1737	404.4
4.	Aim Point to Touchdown	ft.	1349	507.8
5.	100' to Threshold	ft.	2020	293.9
6.	100' to Aim Point	ft.	1533	439.7
7.	100' to Touchdown	ft.	2881	387.8
8.	50' to Threshold	ft.	1144	215.5
9.	Threshold Path Angle	deg.	1.03	0.91
10.	Threshold Wheel Height	ft.	9.15	3.98
11.	Amount Below ILS at TH	ft.	45.9	3.98
12.	Terminal Path Angle	deg.	0.36	0.83
13.	Touchdown Distance	ft.	861	368.8
14.	Ratio: Approach Angle/TH Angle		6.25	11.0
15.	Ratio: Approach Angle/Terminal Angle		11.9	16.9
16.	Ratio: Threshold Angle/Terminal Angle		3.25	4.47

Table XI. Overhead/touch and go/solo/night condition

Condition 1110
N=18

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	4.13	0.63
2.	Approach Aim Point	ft.	498	251.2
3.	Aim Point to ILS GPIP	ft.	1748	251.2
4.	Aim Point to Touchdown	ft.	1471	322.4
5.	100' to Threshold	ft.	1917	161.4
6.	100' to Aim Point	ft.	1419	218.6
7.	100' to Touchdown	ft.	2890	244.5
8.	50' to Threshold	ft.	1047	174.9
9.	Threshold Path Angle	deg.	0.89	1.21
10.	Threshold Wheel Height	ft.	10.68	3.92
11.	Amount Below ILS at TH	ft.	44.3	3.92
12.	Terminal Path Angle	deg.	0.44	0.24
13.	Touchdown Distance	ft.	973	201.3
14.	Ratio: Approach Angle/TH Angle		4.99	5.01
15.	Ratio: Approach Angle/Terminal Angle		12.71	8.03
16.	Ratio: Threshold Angle/Terminal Angle		3.22	4.00

Table XII. Overhead/touch and go/solo/day condition

Condition 1111
N=22

	Parameter	Unit	Mean	Standard deviation
1.	Approach Path Angle	deg.	3.73	0.75
2.	Approach Aim Point	ft.	368	220.9
3.	Aim Point to ILS GPIP	ft.	1618	220.9
4.	Aim Point to Touchdown	ft.	1173	264.4
5.	100' to Threshold	ft.	1963	228.5
6.	100' to Aim Point	ft.	1595	313.7
7.	100' to Touchdown	ft.	2768	240.5
8.	50' to Threshold	ft.	1074	141.3
9.	Threshold Path Angle	deg.	1.31	0.54
10.	Threshold Wheel Height	ft.	9.35	2.9
11.	Amount Below ILS at TH	ft.	45.7	2.9
12.	Terminal Path Angle	deg.	0.39	0.19
13.	Touchdown Distance	ft.	805.2	203.4
14.	Ratio:Approach Angle/TH angle		3.28	1.39
15.	Ratio: Approach Angle/Terminal Angle		13.8	11.45
16.	Ratio: Threshold Angle/Terminal Angle		4.9	4.03

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